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A DUAL-MODE DUAL-BAND BANDPASS FILTER USING A SINGLE SLOT RING RESONATOR

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Abstract—A dual-mode dual-band bandpass filter is designed using a single stub-loaded slot ring resonator. This resonator is coupled to the two external feed lines at two positions spaced at 135° along the slot ring through a pair of microstrip-slotline T-junctions. With a proper choice of the degree of external coupling, the first-order degenerate modes are split to make up the first passband with two transmission poles. The second passband is realized by the second-order degenerate modes, which are stimulated by symmetrically attaching four identical stubs along the slotring. The center frequency ratio of the two operating passbands is controlled by the nature and strength of the external coupling, which is determined by the characteristics of the microstrip open-circuited stubs. Finally, a dual-band filter with center frequencies at 2.4 and 5.2 GHz is designed and fabricated. Measured results verify the design principle and predicted dual-passband performance. Benefiting from an additional transmission zero brought by the transitions,the upper stopband is expanded up to 12.75 GHz with at least 13 dB of rejection.

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1. INTRODUCTION

Designing dual-mode dual-band bandpass filters using ring resonators has become popular in recent years. This is due to the attractive dual-mode characteristic of a ring resonator, which results in compact size and high quality (Q) factor. There are two main design methods. One is to use two dissimilar dual-mode ring resonators with different resonant frequencies [1–6]. The fundamental degenerate modes of each ring resonator are split by simply applying perturbation elements. The challenge of this method in [1–5] actually is to design the input and output coupling configurations for both resonators and to arrange the whole circuit in either a two- or single-layer substrate. By using two resonators, there are many design parameters to consider, which also increases the fabrication difficulties. The other method is to use a single ring resonator [7–12]. In [7, 8], stepped-impedance ring resonators were used to design dual-band filters. By laying out the input/output ports orthogonally (90°), the second-order degenerate modes cannot be separated [7]. A new dual-mode dual-band ring resonator bandpass filter designed by cascading the microwave C-sections was proposed in [9]. But there was no detailed explanation about selecting a proper excitation angle.

Recently a class of dual-mode dual-band bandpass filters was designed based on a single ring resonator with a port excitation angle of 135° or 45° [10–12]. In [10], a dual-band filter was realized by the first- and third-order degenerate modes of the ring resonator with a 135° port separation angle. The frequency ratio of the two operating passbands is properly adjusted by loading eight open-circuited stubs symmetrically along the ring. The two passbands can be also created by the first- and second-order degenerate modes of a ring resonator where the two ports are separated by 135° [11] and 45° [12], respectively. However, the way to control the center frequency ratio of the two passbands has not been well investigated in [11] and [12].

In this paper, an alternative dual-mode dual-band bandpass filter is proposed and designed using a slot ring resonator. Figure 1(a) is the schematic of the proposed filter that consists of a slot ring resonator at the bottom layer and the two microstrip feed-lines at the top layer of a dielectric substrate. Through two microstrip-slotline T-junctions, the microstrip lines are coupled to the ring at the two positions with a separation of 135° along the ring. Based on the technique in [11], the first- and second-order degenerate modes of a slot ring resonator can be synchronously excited to make up the two operating passbands. The remaining part of this work describes the nature of the coupling and its influence on the center frequency ratio of the two passbands.

Finally, a prototype dual-band filter is designed at 2.4 and 5.2 GHz to verify the design principle.

2. PRINCIPLE OF THE PROPOSED SLOT RING RESONATOR

In Figure 1(a), r_1 and r_2 are the inner and outer radii of the ring while the four identical stubs each has a width of w_s and length of l_s. The microstrip lines are of a width of w_m and a length of l_m. Based on the circuit model of a microstrip-slotline transition provided in [13], the equivalent circuit model of the proposed ring resonator is obtained as shown in Figure 1(b), where Z_r and Z_s represent the characteristic impedances of the ring and stubs, θ_r and θ_s are the electrical lengths of one eighth of a ring and stubs, respectively. Z_m and θ_m are the characteristic impedance and electrical length of the microstrip lines. The four slotline stubs are equivalent to four series stubs with short-circuited ends.

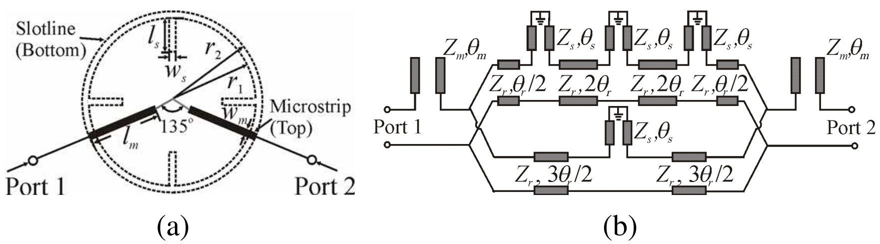

Figure 1. The proposed dual-mode dual-band slot ring resonator. (a) Schematic. (b) Equivalent circuit model.

2.1. Excitation of Two Modes in Two Passbands

Figure 2 illustrates the three sets of simulated results for various stub lengths. For $l_s = 0$ mm, under non-orthogonal external coupling, the two first-order degenerate resonant modes occur at 2.45 and 2.69 GHz, respectively, and make up the first passband. The second passband is suppressed by a transmission zero at 5.37 GHz. As l_s is increased from 1.0 to 2.0 mm, the second-order degenerate modes are split to realize the second passband with one to two poles. Meanwhile, two transmission zeros are generated at both sides of the second passband. With the increment in the stub lengths, the first passband shifts to a slightly lower frequency. So, we can figure out that the bandwidth of the first passband is mainly controlled by the external coupling strength of the microstrip lines and the bandwidth of the second

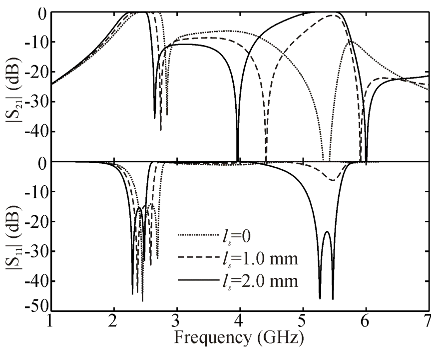

Figure 2. Frequency responses of S-magnitudes under varied stub lengths (l_s). Substrate $\varepsilon_r = 10.8$, thickness = 1.27 mm. $r_1 = 8.24$ mm, $r_2 = 8.26$ mm, $w_m = 0.30$ mm, $l_m = 7.0$ mm, $w_s = 0.20$ mm.

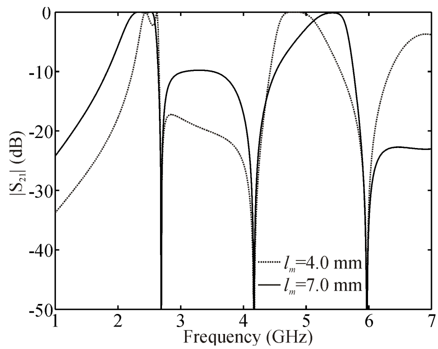

Figure 3. Frequency responses of S_{21}-magnitudes for various microstrip-line lengths (l_m). ($r_1 = 8.24$ mm, $r_2 = 8.26$ mm, $w_m = 0.30$ mm, $w_s = 0.20$ mm, $l_s = 1.5$ mm).

passband can be properly adjusted by both the external coupling strength and the attached four stubs.

2.2. Adjustment of the Frequency Ratio

Figure 3 shows the simulated frequency responses of $|S_{21}|$ for two different microstrip-line lengths. When l_m is 4 mm, the center frequency of the first passband, f_0, is at 2.5 GHz, and the center frequency of the second passband, f_1, is at 4.87 GHz; when l_m is 7 mm, f_0 and f_1 are located at 2.34 and 5.30 GHz, respectively. In these two cases, the center frequency ratio of the two passbands (f_1/f_0) is changed from 1.95 to 2.27. This provides us with the ability to control the center frequency ratio of the two passbands by changing the microstrip lines.

The equivalent admittance of the microstrip lines can be simply expressed as $jY_m \tan\theta_m$. Referring to Figure 3, when both passbands are excited in the capacitive region of the microstrip lines, f_1/f_0 is less than but close to 2; while the first passband is in the capacitive region, and the second passband is moved to the inductive region of the microstrip lines, f_1/f_0 is more than 2. This conclusion can be supported by the values of f_1/f_0 from more examples in Figure 4. When l_m is 4 mm, the microstrip lines act as capacitive elements in both passbands. The three sets of f_1/f_0 are all below but near 2. As

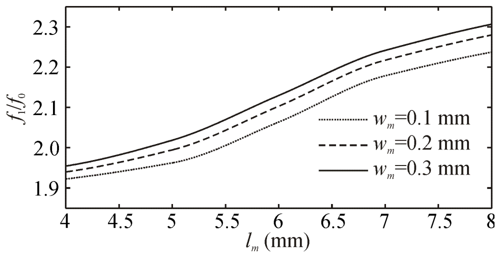

Figure 4. Three sets of frequency ratios of the two passbands versus the lengths of the microstrip lines (l_m). ($r_1 = 8.24$ mm, $r_2 = 8.26$ mm, $w_m = 0.30$ mm, $w_s = 0.20$ mm, $l_s = 2.5$ mm).

l_m increases, the values of f_1/f_0 gradually increase as well. When the microstrip line serves as an inductive element in the second passband, the ratio, f_1/f_0, exceeds 2. Therefore, the location or ratio of the first two resonant frequencies of the proposed slot ring resonator can be adjusted by the nature and strength of the microstrip lines. Moreover, at $\theta_m = 0$ and 180°, two transmission zerosare generated by the microstrip lines. The first zero at DC provides good DC blocking, whereas the second zero appearing at $\theta_m = 180°$ can be properly allocated to expand the upper stopband.

3. RESULTS AND DISCUSSION

Based on the above analysis, a novel dual-mode dual-band bandpass filter is designed on a substrate with a thickness of 1.27 mm and a dielectric constant of 10.8. The center frequencies of the two passbands are specified as 2.4 and 5.2 GHz, with a ratio around 2.17. Figure 5(a) shows the layout of the proposed slot ring filter. Referring to Figure 4 in order to achieve the frequency ratio of 2.17, the widths and lengths of the microstrip lines are optimized and finalized as 0.3 and 6.54 mm, respectively. Figure 5(b) shows a photograph of the fabricated filter with the same dimensions as those in Figure 5(a). Figure 5(c) plots the simulated results from both the circuit model and the full-wave EM simulation [14], and measured results. The two sets of simulated results are well matched with each other in the frequency range up to 8.5 GHz. In both simulated results, the two expected transmission poles visibly exist in the two passbands at the required center frequencies of 2.4 and 5.2 GHz. An additional transmission zero brought by the microstrip lines is excited around 8.0 GHz extending the upper out-of-band rejection. As the frequency exceeds 8.5 GHz, frequency-dispersion and non-TEM properties [13] of the slotline cause

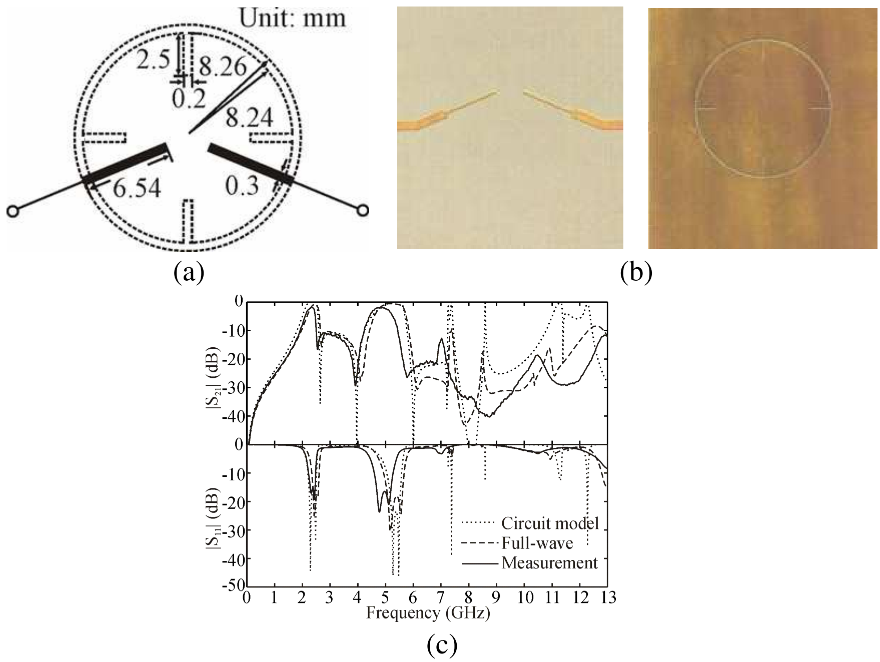

Figure 5. (a) Physical layout of the designed filter. (b) Photograph of the fabricated filter. (c) Circuit and EM simulated and measured frequency responses.

discrepancy between the two sets of the results. In the measured results, the two pairs of transmission poles in the two passbands are also observed. Due to unexpected fabrication tolerance in fabricating a two-layer filter circuit, the measured center frequencies of the two passbands are slightly shifted to 2.28 and 4.90 GHz. However, the frequency ratio of this dual-band filter is still around 2.15, which is very close to our expected ratio of around 2.17. The fractional bandwidths of the two passbands are found to be 14.6% and 18.8%, respectively. The measured insertion loss is around 1.78 and 1.90 dB in the two passbands, respectively. The in-band insertion loss can be improved by packaging the filter into a box to reduce the radiation loss.The measured return loss in both passbands is higher than 16.0 dB. The isolation between the two passbands is better than 11.0 dB from 2.50 to 4.21 GHz. With the help of the transmission zeros around 5.77 and 8.70 GHz, the attenuation in the upper stopband is better than 13.0 dB in the frequency range from 5.50 to 12.75 GHz.

4. CONCLUSION

In this paper, a novel dual-mode dual-band bandpass filter using a single slotring resonator with controllable frequency ratio and a wide upper stopband has been presented and implemented. The principle of the proposed ring resonator is discussed using its equivalent circuit model. Finally, a dual-mode dual-band bandpass filter using the proposed slot ring resonator is designed and fabricated. The measured results have verified our proposed filter topologies.

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